ESD-TDR-64-666

Final Report

FORM PERCEPTION IN VIDEO VIEWING: EFFECTS OF FORM CONTENT AND STEREO ON RECOGNITION

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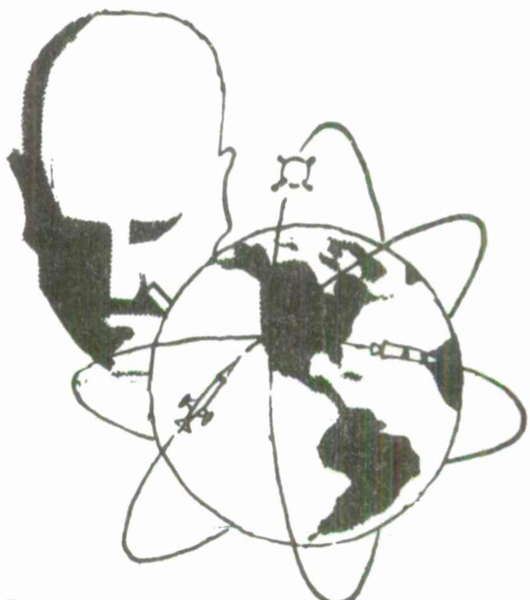
AIR FORCE SYSTEMS COMMAND
UNITED STATES AIR FORCE
L. G. Hanscom Field, Bedford, Massachusetts



Project 9674
Task 967402

(Prepared under Contract AF19(628)328 by the Department of Medical and Biological Physics Airborne Instruments Laboratory, a Division of Cutler-Hammer, Inc. Deer Park, Long Island, New York)

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FOREWORD

This study was conducted by the Department of Medical and Biological Physics of Airborne Instruments Laboratory, a Division of Cutler-Hammer, Inc. Mr. L. W. Paine served as the principal investigator.

The report represents the second part of a two-part study effort under USAF Contract AF 19(628)-328, in support of Project 9674, "Information Transmission for Decision," Task 967402, "Information Content of Visual Forms." The contract was administered by the Display Division, Decision Sciences Laboratory, Deputy for Engineering and Technology of the Electronics Systems Division. Dr. John Coules served as contract monitor.

ABSTRACT

Recognition values, under varying levels of image degradation, were determined for randomly constructed objects of varying complexity (contour turns) and for familiar geometric objects. Values for both familiar and unfamiliar objects were significantly affected by image degradation, but were unaffected by using stereo viewing as compared with nonstereo viewing under the conditions of these experiments.

Variations in the effective inter-objective distance between stereo images had no significant effect on recognition values.

PUBLICATION REVIEW AND APPROVAL

This Technical Documentary Report has been reviewed and is approved.

Donald W. Connolly

DONALD W. CONNOLLY
Chief, Display Division
Decision Sciences Laboratory

Roy Morgan

ROY MORGAN, Col, USAF
Director
Decision Sciences Laboratory

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I. INTRODUCTION AND PURPOSE

Video sensing as an extension of an operator's visual capability is being used for an increasing variety of military weapon systems, manned and unmanned space vehicles, commercial manufacturing processes, and automated training systems. For such uses, the operator's performance can often largely depend upon properly interpreting details presented in the video pictorial image.

Specific knowledge about the effects of variation in several video parameters is becoming more necessary in order to enhance visual interpretation with this most widely used of imaging techniques (for uses beyond those of an acceptable image for an entertainment medium).

The present study deals with variables that might affect the video-viewing process and the physical characteristics of the video image as well as the pictorial information presented. It is essentially an extension of a previous study on video form perception that considered the problems of image degradation and stereo viewing of unfamiliar forms (reference 1). The results of this initial study indicated that:

1. Visual recognition values for video presenting unfamiliar solid forms using a standard 525 commercial video system, are highly sensitive to image degradation effects.
2. Stereo viewing under the conditions of this study did not significantly enhance the recognition of unfamiliar forms.
3. Constructing irregular solid forms on a random basis and equating form faces on the basis of "complexity," as defined by the number of contour turns (reference 2), did not produce equivalence of recognition values for faces randomly chosen from such forms.

4. Visual acuity for video-presented Landolt Ring targets was not closely related to the video recognition.

However, a number of implications, unanswered questions, and limitations in the previous study shaped the intent of the present research and resulted in the division of the problem into three study phases: (1) effects of interobjective distance, (2) effects of form complexity and viewing method on images that were degraded, and (3) effects of video-viewing method and image degradation for familiar objects.

A. PHASE A--EFFECTS OF CHANGING EQUIVALENT INTEROBJECTIVE DISTANCE

It has been generally accepted that the stereoscopic effect in photographic images can be enhanced by increasing the interobjective distance (IOD) of the stereo camera lenses to a value greater than that of the average human interocular distance of 65-mm separation. For example, in aerial photography, this is often accomplished by increasing the "air base" or flight distance between the shooting of the first and second aerial photos of the stereo pair used to make up the final presentation.

For the present study, varying the IOD between images of video stereo pairs made it possible to test directly the effect of this variable upon form recognition and to select an optimum distance for use during the remaining study phases.

B. PHASE B--EFFECTS OF FORM COMPLEXITY AND VIEWING METHOD ON IMAGES OF VARYING DEGRADATION

The purpose of this study phase was to determine the effect of form complexity in unfamiliar forms on video recognition under variations in image degradation and for normal (nonstereo) and stereo viewing conditions.

Complexity (contour turns) has been suggested as having a primary effect on judgments (reference 2). An initial study on recognition under stereo and nonstereo viewing conditions (reference 1) attempted to equate recognition values for sets of randomly constructed forms by using one complexity level throughout--that is, forms having faces of five contour turns only. That study left the complexity concept as a main source of variance in form recognition open to question since the five contour form faces differed significantly from one another. It also led to the decision to study the complexity concept as a separate factor in the present study. Therefore, several sets of random forms with varying numbers of contour turns were constructed for use in this study phase.

C. PHASE C--EFFECTS OF VIDEO VIEWING METHOD AND IMAGE DEGRADATION FOR FAMILIAR OBJECTS

One of the primary questions in attempting to evaluate video viewing methods is whether results obtained with unfamiliar geometric forms are equally applicable to familiar forms. This third study phase presented familiar objects under the same levels of image degradation used for the two previous phases.

When compared with the initial study on video form recognition (reference 1), the present study utilized improved equipment, thereby increasing the probability of each subject achieving and maintaining the desired stereo effect (Section II). The stereo system used not only had a history of commercial application but was more carefully calibrated than had been possible with the equipment of the prior study. In addition, this equipment improvement freed the subjects from a cumbersome and annoying optical system.

II. METHOD

A. TEST FACILITY

The video equipment used in the testing consisted of a Sylvania Model 101 television camera that fed RF signals to a standard 17-inch Admiral television and a standard 10-inch GE television. The 17-inch monitor was mounted at the E (experimenter's) console and the 10-inch monitor was located at the S (subject's) position (Figure 1). In addition, at the subject's position were two monitor attachments; one for stereo viewing and the other for nonstereo viewing (Figure 2). The subject's monitor was viewed through the appropriate attachment depending upon the type of viewing presentation desired.

When viewing the stereo presentation, the subject had access to a toggle switch by means of which he could continually adjust the convergence of the dual images as they changed size on the viewing screen. This control adjusted the position of mirrors in a stereo-captor attached to a Zoomar lens. The lens and the stereo captor were mounted in front of the camera. Thus, for a constant IOD setting, the image size could be changed by variations in the zoom lens and the subject could at the same time make accommodative changes in interimage distance on his screen in order to optimize the stereo presentation.

The stimulus objects to be viewed on the television monitor were placed on a movable cart whose distance relative to the camera determined the effective IOD under the stereo presentation.

By varying the distance between the camera and the object, while holding the object size on the viewing screen constant with the zoom lens, the effective IOD could be

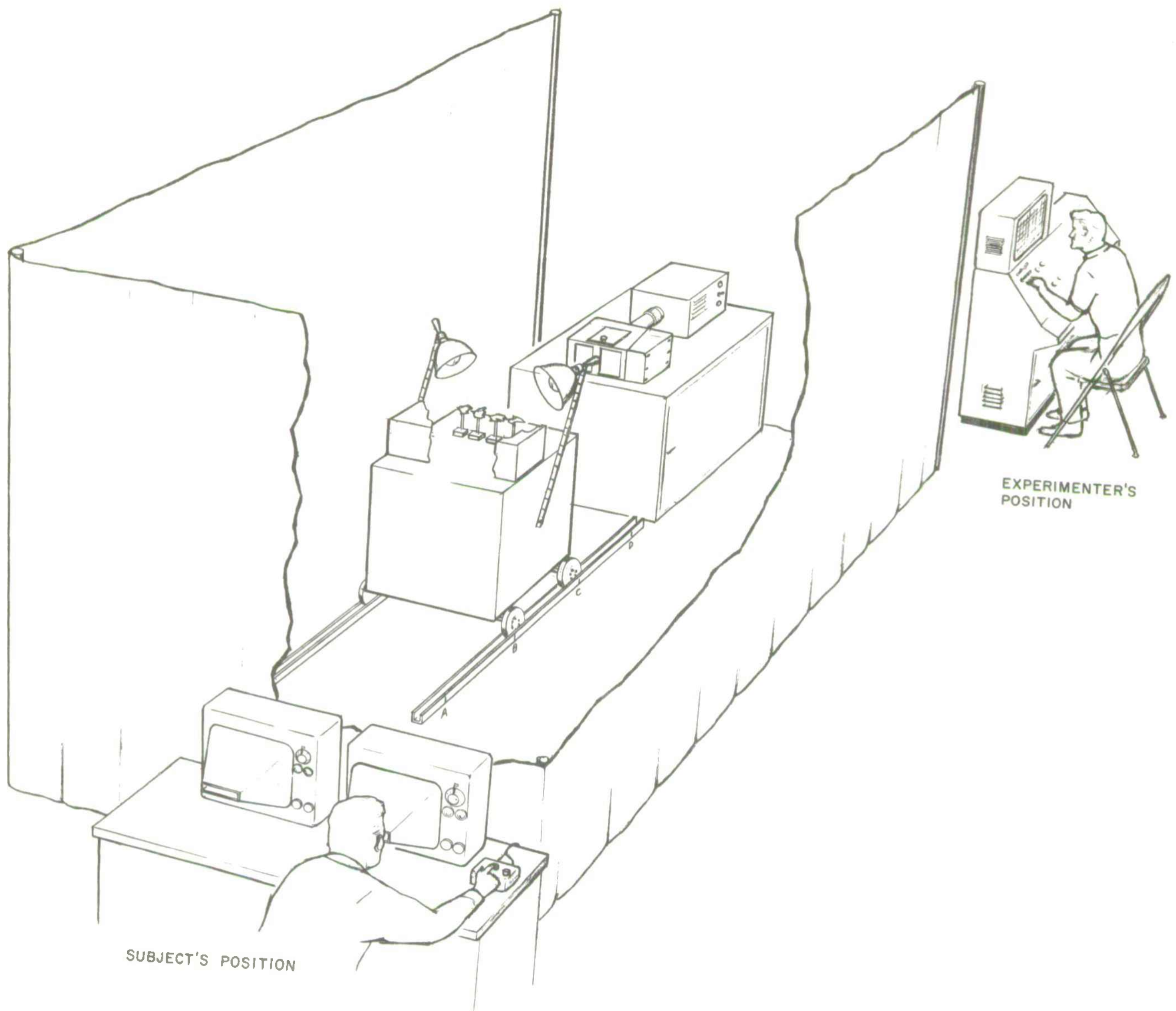

FIGURE 1. TEST FACILITY

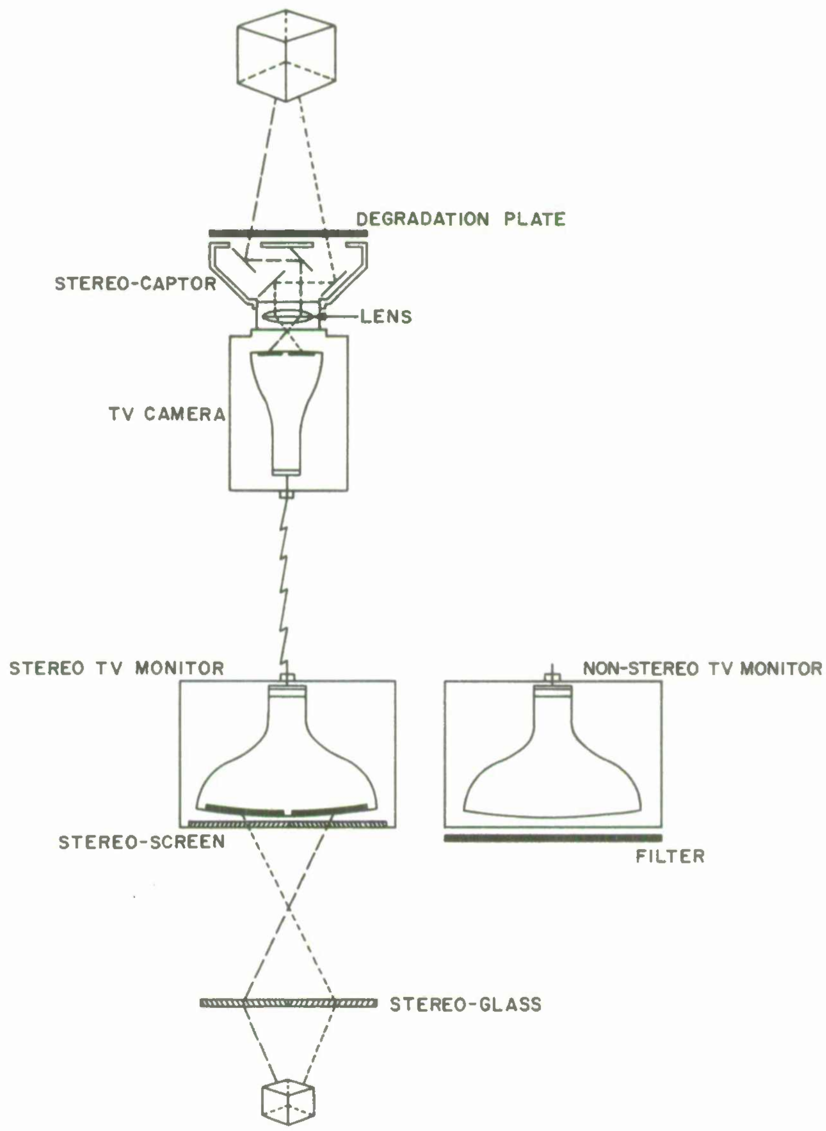

FIGURE 2. STEREO AND NONSTEREO PRESENTATION

changed. Conversely, while keeping the distance between the camera and the object constant and adjusting the zoom lens, the object size could be changed with the IOD remaining constant.

The cart was equipped with two lamps (60 and 150 watts) that illuminated the stimulus objects (Figure 3). The stimulus objects used were positioned in relation to the lights to minimize extreme shadow effects but not to eliminate these effects entirely. The position of these lamps was constant throughout all presentations.

The stimulus objects were degraded to a desired level on the screen by choosing a glass plate (from one of two specially prepared plates sprayed with clear lacquer) and placing it in front of the video camera.

B. STIMULUS DEGRADATION AND BRIGHTNESS

Image degradation with lacquer-sprayed glass plates was controlled by varying the amount of lacquer spray on a large number of such plates and placing these plates in front of a video test pattern for observation on the video screen. Using the judgment of four observers it was possible to specify the decrease in the percentage of degradation achieved by placing lacquered glass plates in front of the test pattern and to limit these plates to the two that provided degradation at the 45 and 70 percent levels.

It was also necessary to maintain equivalent screen brightness between the stereo and nonstereo viewing conditions since the polarized lenses used with the stero attachment reduced the overall screen and image brightness by 82 percent.

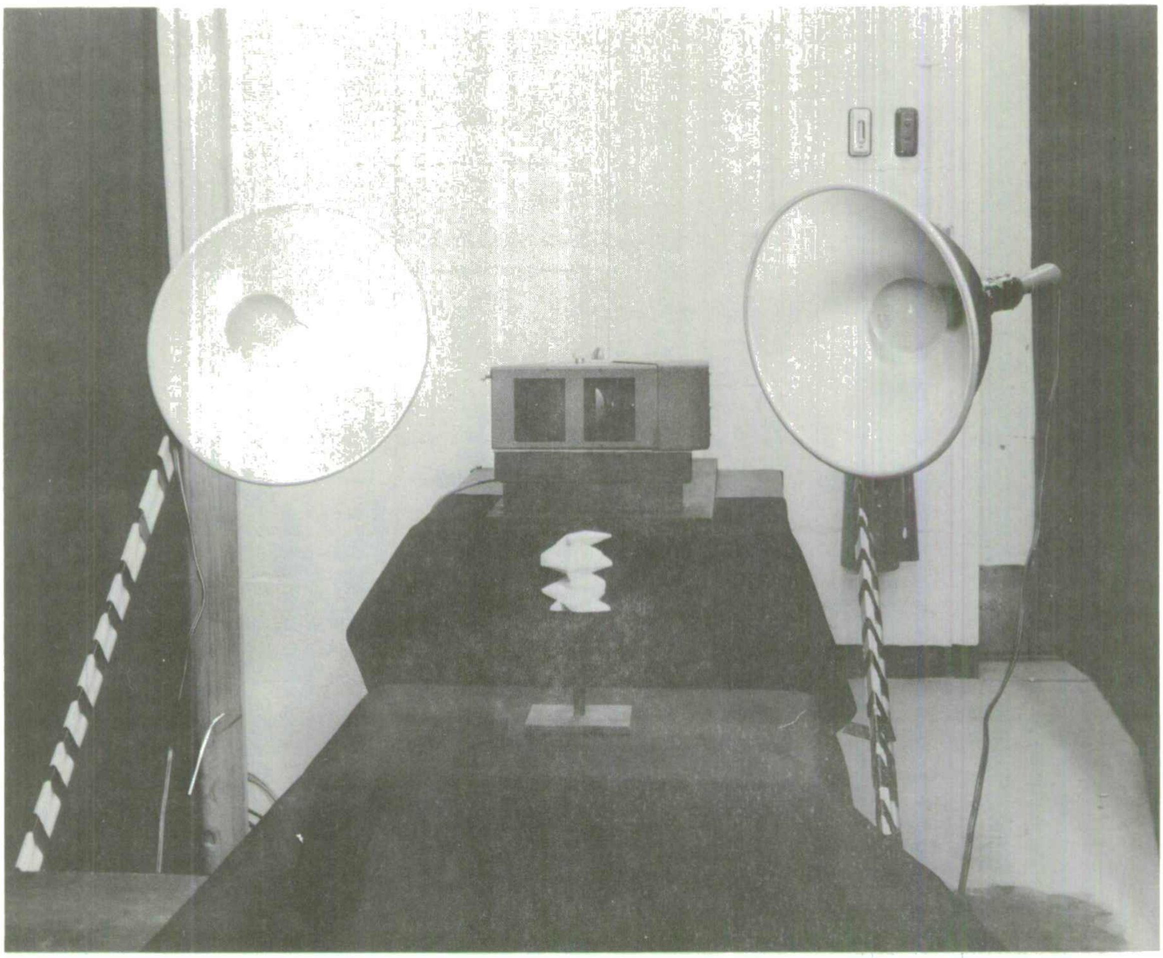

FIGURE 3. POSITIONING OF OBJECT CART

To achieve the brightness equivalence, neutral density filters,* placed in front of the screen during normal viewing, reduced the screen brightness to a level equal to that resulting from the stereo polaroid filter. It should be noted that these filters did not distort or degrade the video image in any way.

C. STIMULUS FORMS

One set of 12 solid objects that were constructed for two of the three study phases were random unfamiliar forms. Within this set were three groups of four forms each, each group having a different level of form complexity. One group had all faces displaying three contour turns and the other two had five and seven contour turns for any form. Each form was identified by number and had designated on it arbitrarily chosen North (N), South (S), East (E), and West (W) faces so that the form faces could be oriented during the study presentations. Appendix A describes the construction of the forms.

In addition to the twelve unfamiliar forms, three familiar solids (sphere, cube, and pyramid) were also constructed for presentation in a third study phase.

D. IOD SETTING

The effective IOD could be varied as a function of the physical distance between the camera zoom lens and the objects in the camera field of view. This relationship is shown in Figure 4. The reference (normal) IOD of 65 mm is at 11 feet between camera and test objects.

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* The filters were ozalid KBz transparencies developed in the Ozalid machine to a level that gave an 82-percent decrease in overall screen brightness. These could then be placed on the monitor under the nonstereo condition.

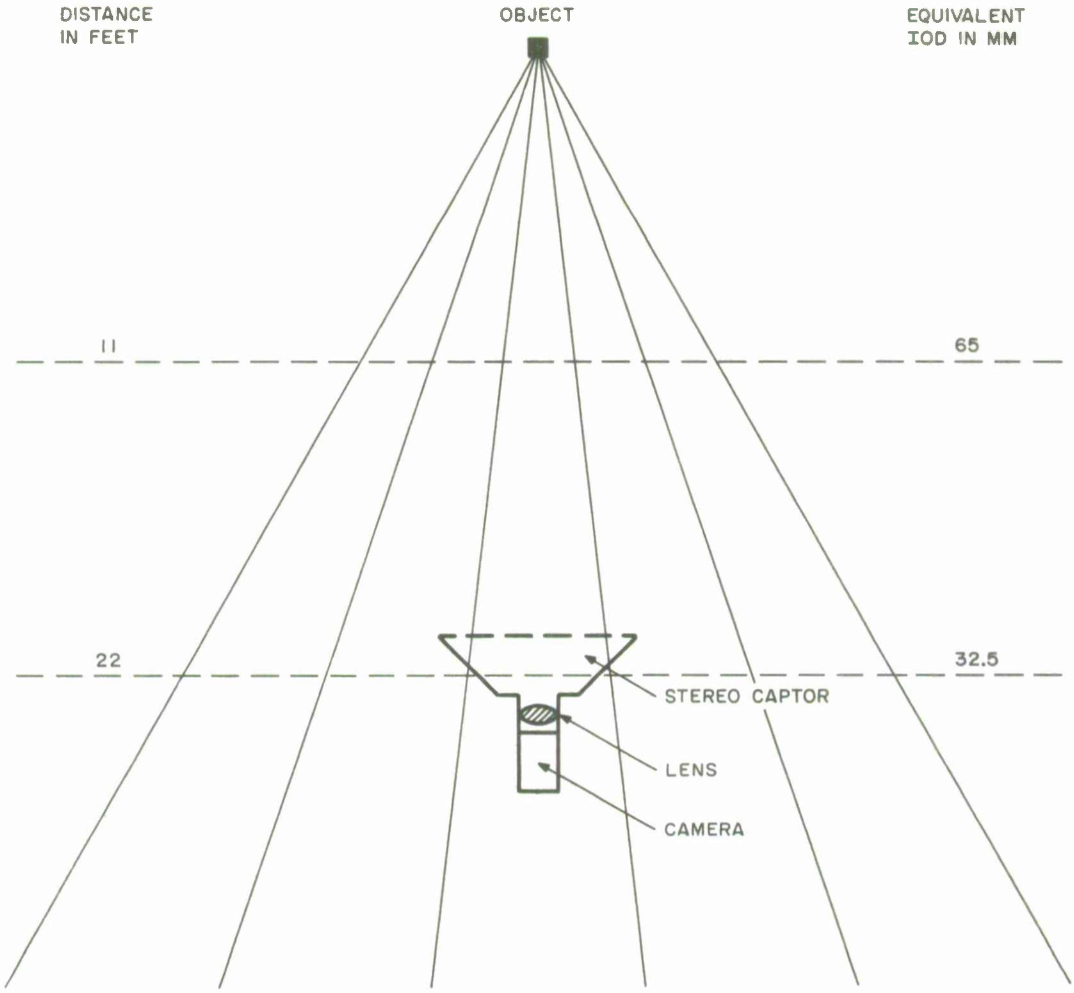

FIGURE 4. RELATIONSHIP BETWEEN EFFECTIVE INTEROBJECTIVE DISTANCE AND PHYSICAL DISTANCE

When the camera is moved back to 22 feet, the IOD of 65 mm is equivalent to an effective IOD of 32.5 mm at 11 feet. The size of the object was maintained the same at the various distances by changing the zoom lens setting. Thus, IOD setting and object size could be maintained independently. Table 1 indicates the effective IOD for the camera to object distances used.

TABLE 1

EFFECTIVE IOD WITH OBJECT VIEWED AT
11 FEET FOR VARIOUS CAMERA-TO-OBJECT DISTANCES

Camera-to-Object Distance (feet)	Effective IOD with 11-foot Separation Between Object and Camera (mm)
14.0	51
11.0	65
9.0	80
7.5	95

E. RECOGNITION MEASURES

Measures of subject recognition were obtained in terms of image size on the experimenter's video monitor. Size was read from a fine-line grid with squares of 6.35 mm superimposed on the monitor. After each trial, the experimenter recorded the height of the test form in terms of the number of squares subtended.

This method of determining recognition measures was necessary since no variation in physical distance occurs between the camera and the forms when a zoom lens is used. The object appears larger on the screen only because of appropriate focal changes in the lens system.

III. PROCEDURE

Prior to the beginning of the test trials, the subject was seated at the viewing monitor, and instructions were read to him regarding the purpose of the study and his particular task (Appendix B). Specific training in achieving stereo was given, including the means of obtaining an optimum stereo effect by adjusting the convergence control. The subject practiced achieving stereo at several image sizes under an effective IOD setting of 65 mm and zero image degradation using a pyramid-shaped object. When he was able to achieve the stereo effect fairly readily he was also shown a sample of the unfamiliar objects that would be presented in the first two study phases. The video-presented test-form faces were randomly positioned among alternative forms during a trial.

A. PHASE A

For a given trial, the subject viewed through the stereo monitor, the test-form face selected as the standard for that trial. After he had achieved a stereo effect, the subject viewed this unfamiliar form on the screen for 30 seconds under optimum resolution and at an image size that subtended 3 degrees of visual arc.

Following the presentation of the standard form, the subject's stereo monitor was covered for approximately 50 seconds and then uncovered to reveal 4 unfamiliar stimulus forms below recognition levels. One of these four forms was the previously viewed standard form face (in the same orientation) randomly assigned a position among the three alternatives.

The experimenter increased the image size on the video screen in small increments by adjusting the zoom lens. The subject was to indicate when he recognized the standard form by indicating its position among the four forms on the screen (first, second, third, or fourth from the left). After the first correct response, the experimenter increased the form size by one increment and required one additional recognition response. When two consecutive correct responses were given, the trial was completed and the number of grid boxes subtended by the test form were recorded as the recognition measure. This criterion for correct responses was chosen in order to minimize errors due to guessing and thus stabilize response values.

Variations in the four IOD settings (51, 65, 80, and 95 mm) and the degradation levels (0, 45, and 70 percent) were preset by the experimenter before each trial according to a predetermined random order of presentation.

Each of six subjects were tested twice under 12 possible combinations of the study conditions.

B. PHASE B

In this phase, the same basic procedure as in Phase A was used except for the variation in test forms and viewing method. Presentation of forms having three, five, and seven contour turns were varied randomly from trial to trial along with the three degradation levels. Stereo and nonstereo viewing methods could not be varied randomly in a trial-by-trial manner since the change from one method to another required too long a period of time. Therefore, these were counterbalanced for order of presentation from subject to subject with all stereo trials followed by all nonstereo for one subject and the reverse order for the next subject.

All presentations were made at the 65 mm IOD level chosen on the basis of Phase A results. Each of six subjects completed one trial under each of 18 possible study conditions.

C. PHASE C

This study phase required the subject to recognize one of three familiar objects (sphere, pyramid, or cube) from among a group of four objects. One of the forms was presented as the standard, in the same manner as in the two previous study phases. The subject was then required to recognize the form from among three others, with each of the three alternatives being unfamiliar objects of three-contour complexity. The image degradation level was varied randomly from trial to trial and viewing condition (stereo and nonstereo) was again counterbalanced from subject to subject with the IOD set at 65 mm. Five subjects completed one trial under all 18 possible conditions.

IV. RESULTS AND DISCUSSION

A. PHASE A

Table 2 is a summary of the analysis of variance for the test of the four IOD settings under the three levels of degradation. For this study phase as for the remaining two phases, the experimental design is that of subjects by treatments with subject replication.

No significant differences in recognition scores were apparent among the IOD settings. Relevant reasons which might account for this lack of difference in IOD settings include inadequate range of IOD settings, criterion of two successive correct responses, insufficiently trained subjects, and high similarity of forms. The criterion of two successive correct responses might have raised the recognition levels equally for all the settings thereby eliminating the detection of any real effect. Insufficiently trained subjects would tend to increase subject variance and reduce the possibility of getting significant differences.

Difference in values occurs only for the degradation levels (as expected). There are also significant effects for subjects as shown by the significant replication (block) effect. Since there is no interest in subjects as a separate factor for study purposes this block effect term serves to remove the effects of subjects and subjects by treatments interaction along with the consolidated effect of subjects under the two treatments. Thus, a more precise error term is obtained.

Since there were no IOD differences or IOD interaction with degradation levels, the "normal" IOD setting was chosen (65 mm) and the cart carrying the stimulus forms was set at the appropriate distance from the camera zoom lens to give an effective IOD of 65 mm for the remaining study phases.

TABLE 2

SUMMARY OF ANALYSIS OF VARIANCE

Study Phase A

Source	Sum of Squares	df	Mean Squares	F Ratio
IOD Setting (I)	3.79	3	1.26	0.63
Degradation Level (D)	27.65	2	13.83	6.92*
Interaction (I x D)	23.23	6	3.87	1.94
Replication (block effect)	137.15	5	27.43	13.72*
Error	112.55	55	2.04	
Total	304.37	71		

* Significant at the 0.01 level.

B. PHASE B

This phase, which was intended as a test of viewing methods and complexity under varying degradation levels, resulted in no significant effects on recognition for any main effect other than degradation level ($P < 0.05$). The mean recognition values for Phases A and B are plotted as a function of the three degradation levels in Figure 5.

A summary of the analysis is presented in Table 3. Two missing data points of the 108 were not available and had to be approximated by an estimation technique (reference 3).

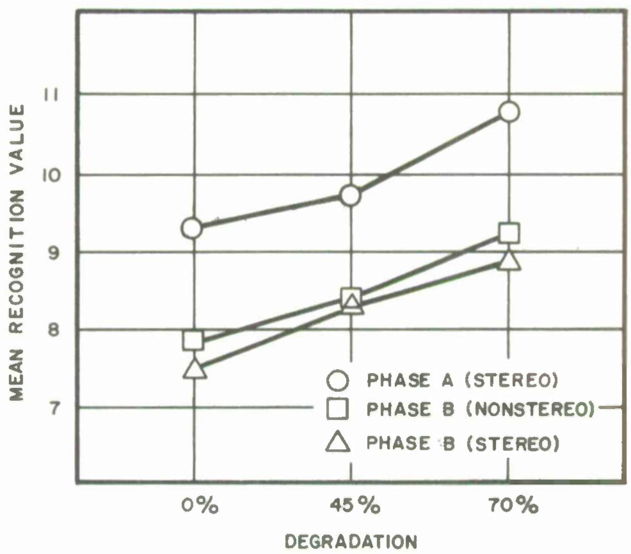

FIGURE 5. PROFILE OF SIMPLE INTERACTION EFFECTS FOR DEGRADATION LEVELS - PHASES A AND B

TABLE 3

SUMMARY OF ANALYSIS OF VARIANCE

Study Phase B

Source	Sum of Squares	df	Mean Squares	F Ratio
Contour Turn (C)	15.78	2	7.89	1.92
Degradation (D)	37.26	2	18.63	4.53*
Viewing Method (V)	7.06	1	7.06	1.72
Interaction (C x D)	31.77	4	7.94	1.94**
Interaction (C x V)	9.02	2	4.51	1.10
Interaction (D x V)	2.61	2	1.30	0.32
Interaction (D x V x C)	15.78	4	3.94	0.96
Replication (block effect)	35.70	5	7.14	1.73
Error	393.62	85	4.11	
Total	548.60	107		

* Significant at the 0.01 level.

** P $\approx$ 0.10 level.

No significant interactions at the 0.05 level were found although a contour turns by degradation interaction approaches the 0.10 level. This probably falls short of significance because of the relatively small sample size. A plot of this interaction is worth consideration and is shown in Figure 6. The effect is seen as a pattern of increasing threshold with increasing complexity (contour turns) under the 0 and 45 percent degradation level, which is reversed for the extreme degradation condition (70 percent). At the high degradation level, the seven contour-turn form tends, in effect, to become a "simpler" form by losing the detailed segments of the contour and becoming easier to recognize on the basis of overall shape. The other forms, having fewer contour turns, tend to retain their complexity with perceivable contour detail despite the image degradation.

However, any interpretations are tenuous owing to the low level of significance and indicate only that this particular result requires future verification.

The fact that viewing method (stereo-nonstereo presentation) shows no significant difference in recognition supports findings from the previous study of video form recognition (reference 1).

C. PHASE C

Using familiar geometric forms under the two viewing methods and the three levels of image degradation produce the results for the analysis of variance contained in Table 4. Degradation is again significant, in its effect on recognition values, but viewing method also appears as significant, with lower mean values occurring under the nonstereo viewing method. Any significant results or conclusions drawn, however, are open to question and probably artifactual, since for two of the 18 study conditions (cube under zero

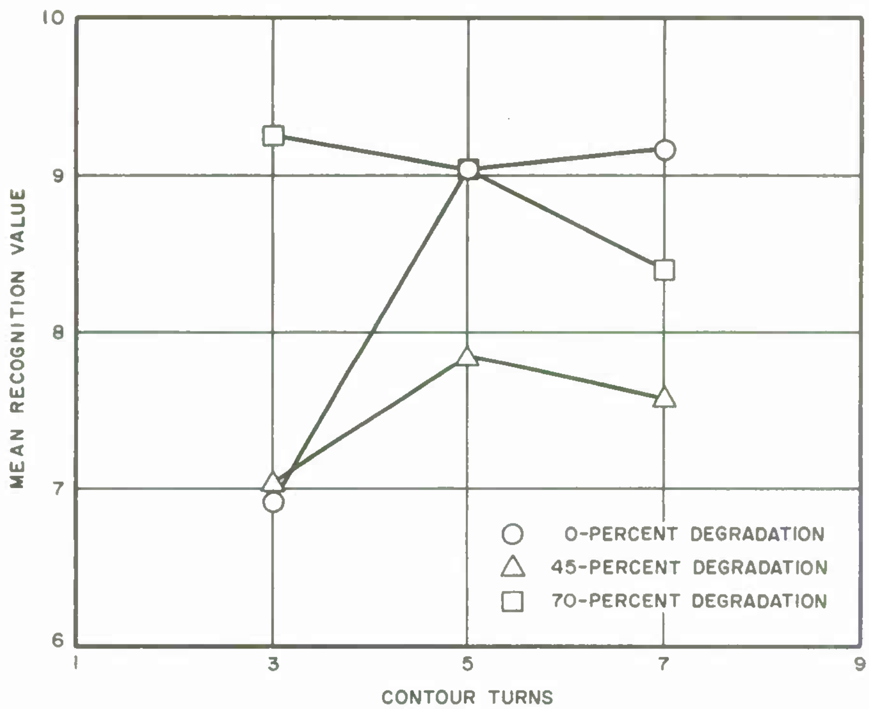

FIGURE 6. PROFILE OF SIMPLE INTERACTION EFFECTS FOR CONTOUR TURNS - PHASE B

TABLE 4

SUMMARY OF ANALYSIS OF VARIANCE

Study Phase C

Source	Sum of Squares	df	Mean Squares	F Ratio
Viewing Method (V)	30.97	1	30.97	13.47*
Forms (F)	5.76	2	2.88	1.25
Degradation Level (D)	76.22	2	38.11	16.57*
Interaction (V x F)	0.52	2	0.26	0.11
Interaction (V x D)	7.81	2	3.91	1.70
Interaction (F x D)	8.26	4	2.06	0.90
Interaction (V x F x D)	23.56	4	5.89	2.56**
Replication (block effect)	35.04	4	8.76	3.81*
Error	156.02	68	2.30	
Total	344.16	89		

* Significant at the 0.01 level.

** Significant at the 0.05 level.

degradation and nonstereo and sphere under 70-percent degradation and nonstereo) data were missing. These were substituted for by the missing data technique discussed by Winer (reference 3).

All of these missing data occurrences were under the nonstereo viewing condition and resulted from errors in presenting the order of study conditions. The missing data could not be replaced since the equipment was dismantled immediately after the third study phase was completed.

Since the substitution for missing data constitutes a linear approximation there is also a minimal chance of uncovering any interactions which may have been present had all of the data been available. However, a triple interaction reaches significance at the 0.05 level. The presence of this interaction, in light of the missing data, leaves any interpretation of main effects open to question and does not warrant the attempt to pinpoint the source of the interaction.

To test the effects of the study conditions without relying upon approximation for missing data, tests were computed for differences between means under each of the three study conditions (three familiar geometric forms, two viewing methods, three levels of degradation). The seven possible T tests resulted in significant differences between means that parallel the results of the F-ratios obtained by using approximation for missing data. That is, there are significant differences between means for viewing methods ($T = 2.45$, $P < 0.02$) and degradation level ($T_{0-45\%} = 3.68$, $P = 0.01$; $T_{0-70\%} = 3.55$, $P = 0.01$; $T_{45-70\%} = 2.44$, $P = 0.05$), but not for threshold values for geometric forms ($P > 0.10$ for all three cases).

V. CONCLUSIONS

Within the limitations of the present study--that is, small sample size, missing data, etc.--and based upon a previous study of video form recognition, the results indicate a lack of any clear superiority of stereo viewing for a form-recognition task. However, certain data inadequacies, as discussed in the body of this report, leave any definitive conclusions regarding the effects of stereo for a recognition task open to question and varification. Attempts to enhance this stereo effect by varying the IOD between the images viewed did not change the effects on recognition significantly.

Degradation of the video image results in a corresponding reduction in recognition for both familiar and unfamiliar forms. There is also limited evidence that the degradation level may interact with form complexity for unfamiliar forms.

Complexity, as a separate variable, does not appear to exercise a significant main effect on recognition. In fact, the concept of complexity, as being primarily determined by number of contour turns in a form face, may only be applicable to forms with a limited number of contour changes (about 5). Beyond this, an increase in contour turns would appear to have minimal effect since these blend to form essentially a single contour at near recognition levels.

In the present study, we believe that there was adequate control of the physical video conditions, but that of the perceptual quality of the stimulus forms not sufficient to ensure control of the variables involved. A primary example is that of shadow effects on recognition. In fact, leaving the light sources at a constant position in relation to the stimulus objects only served to ensure uncontrolled variation in shadowing since the different facets of each form face (of the same object) resulted in their casting different shadows from the same light source orientation. However, no suitable criteria are known that would have permitted changes in lighting orientation in order to control shadow effects on recognition (reference 4).

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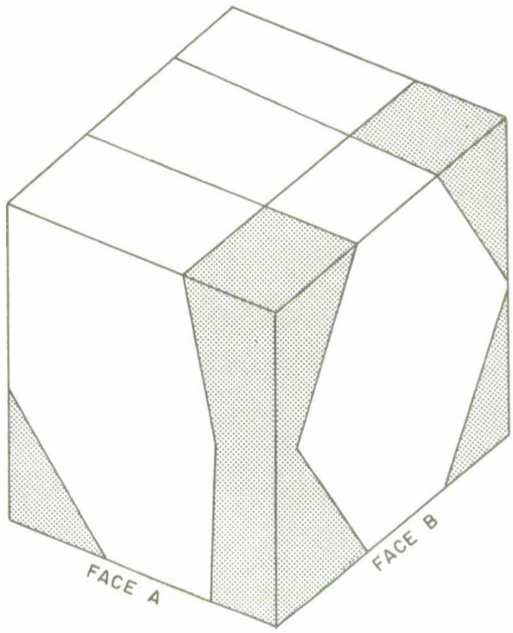
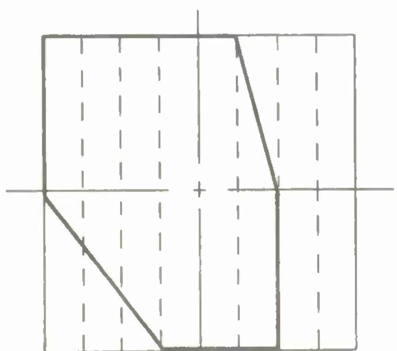
APPENDIX A
CONSTRUCTION OF RANDOM UNFAMILIAR FORMS

Each face was constructed by randomly selecting units from 1 to 4 to represent the distance (in squares on graph paper) from the form centerline (Figure A-1). For example, in constructing the three contour forms, these distances from the centerline were taken first at three equidistant points, thereby forming three contour objects. Two such form faces were plotted and set at right angles and then cut into a 1-inch cube of wood. The resultant forms were painted flat white and mounted.

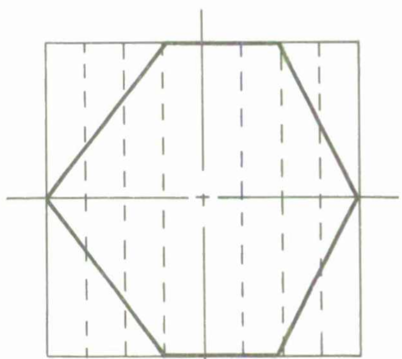
The same was done taking five equivalent distances and seven equivalent distant points, thereby forming five and seven contour objects, respectively.



3-CONTOUR OBJECT



FACE A



FACE B

FIGURE A-1. CONSTRUCTION OF RANDOM UNFAMILIAR FORMS

APPENDIX B
INSTRUCTIONS TO SUBJECT

The subject is seated and the following instructions are read to him.

"The visual tests in which you are to take part will involve your ability to observe and recognize forms that will be presented to you on a TV screen. For the first portion of the study, you will be looking at a TV monitor through this viewing hood which is designed to give you a non-three-dimensional effect when you look at various forms."

"You will be asked to study a form carefully, for a period of time, and a few moments later to pick it out from among a group of four similar forms. The four forms will appear very small, but will become larger as the camera moves closer. The camera will stop periodically and you will be asked, whether or not you can identify the test form. If you cannot, the camera will continue to move closer and the forms will become larger. When you are fairly confident that you can pick out the test form, do this by identifying its position as first from the left, second from the left, and so on. Try not to make any wild guesses in identifying the form, but if you think you see it don't hesitate to make the identification."

APPENDIX C
RAW DATA

Phase A

Trial	IOD Setting (mm)	Degradation Level (percent)	Objects (test object circled)	Recognition Scores (number of lines) Subject No. 1	2	3	4	5	6
1	80	70	7N 5E 6S 8W	8	8	18	14	14	18
2	51	0	6W 8N 5W 7E	7	10	16	7	10	14
3	51	70	8E 5N 7W 6N	8	8	10	8	18	13
4	65	0	7S 6W 8N 5E	7	7	9	9	10	9
5	80	45	7W 8S 5E 6N	8	7	12	16	10	10
6	95	45	6S 5E 8E 7E	8	7	16	8	10	12
7	80	0	7W 6N 8N 5W	7	8	12	10	10	10
8	51	45	5S 6E 7N 8E	7	9	8	12	15	10
9	95	0	8S 6S 5W 7W	8	8	8	12	10	8
10	65	45	5S 7N 6N 8N	7	9	10	9	9	8
11	65	70	7E 5W 8N 6W	10	7	18	11	16	9
12	95	70	6N 8S 7S 5N	8	8	10	9	16	8
13	95	45	6S 5E 8E 7E	8	8	10	8	10	16
14	80	45	7W 8S 5E 6N	8	7	12	10	12	8
15	65	0	7S 6W 8N 5E	12	7	8	10	8	10
16	51	70	8E 5N 7W 6N	9	5	11	12	18	10
17	51	0	6W 8N 5W 7E	10	11	10	7	12	7
18	80	70	7N 5E 6S 8W	8	8	7	10	12	12
19	95	70	6N 8S 7S 5N	8	9	8	10	16	8
20	65	70	7E 5W 8N 6W	16	8	16	13	10	10
21	65	45	5S 7N 6N 8W	8	7	10	9	8	8
22	95	0	8S 6S 5W 7W	8	8	10	8	10	11
23	51	45	5S 6E 7N 8E	12	6	7	7	16	11
24	80	0	7W 6N 8N 5W	8	8	8	9	14	8

Phase B

	Trial	IOD Setting (mm)	Degradation Level (percent)	Objects (test object circled)	Recognition Scores (number of lines) Subject No. 1	2	3	4	5	6
Stereo	1	65	45	7 S, 6 W, 8 N, 5 E	6	9	8	16	14	6
	2	65	70	1 S, 3 N, 2 N, 4 W	8	12	8	6	14	8
	3	65	0	6 S, 5 E, 8 E, 7 E	10	8	10	6	8	8
	4	65	45	2 W, 4 N, 1 W, 3 E	6	10	6	6	7	8
	5	65	45	9 S, 10 E, 11 N, 12 E	6	9	9	8	10	8
	6	65	0	11 W, 10 N, 12 N, 4 W	6	7	8	6	9	8
	7	65	0	3 N, 1 E, 2 S, 4 W	8	9	6	8	10	7
	8	65	70	6 W, 8 N, 5 W, 7 E	10	10	10	18	8	9
	9	65	70	12 S, 10 S, 9 W, 11 W	8	12	12	6	6	10
Nonstereo	10	65	45	10 S, 9 E, 12 E, 11 E	7	11	8	8	12	14
	11	65	0	5 S, 6 E, 7 N, 8 E	8	8	6	6	6	10
	12	65	0	11 W, 10 N, 12 N, 9 W	8	8	10	6	6	8
	13	65	70	3 S, 2 W, 4 N, 1 E	9	10	10	6	12	8
	14	65	0	3 W, 4 S, 1 E, 2 N	6	6	7	6	6	6
	15	65	70	12 S, 10 S, 9 W, 11 W	6	9	11	6	9	6
	16	65	45	5 S, 7 N, 6 N, 8 W	6	9	11	12	6	6
	17	65	45	3 E, 1 W, 4 W, 2 W	6	10	6	6	6	6
	18	65	70	6 W, 8 W, 5 W, 7 E	9	8	6	14	6	10

Phase C

	Trial	IOD Setting (mm)	Degradation Level (percent)	Objects*				Recognition Scors (number of lines) Subject No. 1	2	3	4	5
Stereo	1	65	45	P	2 W	4 N	1 E	7	8	10	7	10
	2	65	70	S	3 N	2 N	4 W	6	9	10	8	8
	3	65	0	2 S	1 E	P	3 E	6	6	6	6	6
	4	65	45	2 W	4 N	S	3 E	8	9	12	8	10
	5	65	45	1 S	C	3 W	4 E	6	8	10	8	9
	6	65	0	3 W	2 N	S	1 W	6	6	9	10	11
	7	65	0	C	1 E	2 S	4 W	6	6	6	6	8
	8	65	70	2 W	P	4 N	3 E	11	16	6	9	9
	9	65	70	4 S	2 S	1 W	C	10	12	10	7	8
Nonstereo	10	65	45	2 S	1 E	C	3 E	6	6	6	7	9
	11	65	0	1 S	P	3 N	4 E	6	6	6	6	6
	12**	65	0	3 W	2 N	C	1 W	6	6	6	7	6
	13**	65	70	S	2 W	4 N	1 E	9	7	12	8	11
	14**	65	0	3 W	4 S	1 E	C	6	10	6	6	6
	15**	65	70	4 S	2 S	1 W	S	9	8	12	8	9
	16	65	45	P	3 N	2 N	4 W	6	6	8	6	6
	17	65	45	3 E	1 W	4 N	S	6	6	8	6	8
	18	65	70	2 W	4 N	P	3 E	7	8	11	6	9

* P = Pyramid, S = sphere, C = cube.

** Due to an error, trials 12 and 14, 13 and 15 are the same. The two recognition threshold values for each set of trials were averaged giving a single value for each object and degradation combination. The values for the two missing combinations of nonstereo-zero degradation sphere and nonstereo - 70 percent degradation cube were computed by a missing data technique as discussed by Winer (reference 3).

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